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CURRENT CANADIAN ACTIVITIES IN RAPID SOLIDIFICATION TECHNOLOGY (RST)

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ABSTRACT

Rapid solidification technology (RST) is evolving quickly on a world-wide basis and is likely to lead to a number of significant commercial developments. A survey of Canadian activities in RST reveals that there has been little development of this technology in Canada. Although metallic glasses and processing techniques are being studied at a number of universities, and several companies and not-for-profit institutions are undertaking exploratory projects, only one Canadian company maintains an active program of alloy and process development in RST.

Means of promoting the development of RST in Canada are suggested.

LABORATOIRES DU RECHERCHE EN MÉTALLURGIE PHYSIQUE
RAPPORT PRM/LRMP 84-79(TR)

ACTIVITÉS COURANTES EN TECHNOLOGIE
DE SOLIDIFICATION RAPIDE (TSR)

par

L.E. Collins et D.W.G. White

RÉSUMÉ

La technologie de solidification rapide (TSR) se développe rapidement de par le monde, et en conséquence, cela laisse à présager à de nombreux développements commerciaux. Une étude récente nous démontre qu'il y a eu très peu de progrès dans le développement de cette technologie au Canada. Quoique les métaux amorphes et les techniques de développement sont étudiés dans certaines universités, et que plusieurs compagnies et organisations sans but lucratif font des projets exploratoires dans ces domaines, une seule compagnie canadienne a un programme actif en recherche d'alliage et de méthode de technique de solidification rapide (TSR).

Des moyens de promouvoir au développement des TSR au Canada sont suggérés.

INTRODUCTION

Since the mid 1970's, the technology of rapid solidification (RST) has evolved rapidly as a means of producing metals and alloys with new and/or enhanced properties. To date, efforts have concentrated on determining the effects of rapid solidification on microstructure and assessing the degree of property enhancement that is obtained through microstructural refinement. Now that the potential of rapid solidification has been clearly demonstrated, major efforts are being devoted to developing commercial products utilizing RST. Although some experts predict that another decade may pass before RST has a significant commercial impact, a few products have already reached the market and many more are likely to follow. The current state-of-the-art of RST is discussed in detail in a complementary report (1).

In view of the anticipated development of RST, CANMET is initiating a program of research in this field. A survey of Canadian RST activities was completed in the fall of 1984 to provide background to this program. The survey was conducted by means of laboratory visits and telephone interviews with the individuals listed in Table 1. In the following text, the programs and interests of Canadian organizations are briefly described in one of three categories: Industry, Government and Research Institutes, and University.

INDUSTRY

The industrial development of rapid solidification in Canada is not widespread. As yet, Alcan is the only company with a dedicated development program encompassing production, processing and application of rapidly-solidified materials. However, at least two Canadian utilities are engaged in programs to evaluate the performance of prototype distribution transformers containing metallic-glass cores.

ALCAN INTERNATIONAL LTD.

Alcan maintains a large effort in RST research and development employing about 8 PY's in the Kingston laboratory and 5 PY's overseas. Alcan considers rapid solidification to include those processes which produce cooling rates in excess of 100°C/s, as this cooling rate is faster than that obtained by conventional casting practices and is sufficient to produce some solid solution supersaturation in aluminum alloys. Alcan has developed a

number of processes which produce rapidly-solidified material. At the lower cooling rates within this range, DC and twin-belt casters are used for the commercial production of plate of 0.6 to 1.9 cm thickness. For higher cooling rates, melt spinning, twin roll casting, and fiber production by melt extraction have all been explored. As well, Alcan operates a powder production facility in the U.S.

Alcan has investigated the effects of rapid solidification on a wide range of alloys, and there is particular interest in the development of alloys with structures stabilized by slow-growing intermetallic precipitates for high temperature (200 to 300°C) applications.

CANADIAN ELECTRICAL ASSOCIATION (CEA)

The CEA is co-sponsoring a project with Allied Corp. to design and construct 25 kW power distribution transformers with metallic-glass cores. Less heat is generated by the metallic-glass core than by the conventional silicon-iron core and it should be possible to use a coolant with lower heat conduction properties than the oil now used. The \$650 000 project will seek to develop an SF₆ gas insulated transformer that dispenses with the need for oil cooling. Initially, the project will examine the feasibility of such a transformer. In later stages, a prototype will be constructed and tested, the testing to be carried out by Ontario Hydro. The CEA would also like to involve a Canadian transformer producer in this project.

HYDRO QUEBEC

Hydro Quebec is starting a program to develop metallic glasses for transformer applications. At present, Hydro Quebec is funding a project at McGill University which will compare the magnetic properties of metallic glasses with Fe-6Si alloys. In the near future, Hydro Quebec intends to construct rapid-solidification equipment for producing metallic glass strip with the eventual goal of producing sufficient material to construct prototype transformers. A simultaneous program will consider transformer design to optimize the advantages offered by metallic glasses.

SASKATCHEWAN POWER

Saskatchewan Power is currently testing four prototype 50 kVA transformers containing metallic-glass cores. Three of the transformers were obtained from McGraw-Edison and one from Federal-Pioneer. At present the

transformers are undergoing routine testing. A problem with the core clamps which is unrelated to the performance of the metallic glass has temporarily slowed the project. However, upon completion of testing, the transformers will be put into service and their performance monitored.

SIGMA SECURITY INC.

The only commercial application of metallic glasses in Canada is that of Sigma Security, which makes use of the material in anti-shoplifting systems. Small strips, 2.5 mm wide by 20 μ m thick, of cobalt-base metallic glass are inserted in the items to be protected. The magnetic glass triggers an alarm if not demagnetized before passing through a detection system. The high-permeability metallic glasses are readily "de-activated", and the strip may be cast directly from the melt eliminating the need for further processing and minimizing production costs.

Sigma Security requires approximately 1.5 metric tons of metallic glasses annually. While at present the metallic glass is purchased offshore, the company has indicated an interest in locating a Canadian supplier.

GOVERNMENT AND RESEARCH INSTITUTES

DEPARTMENT OF NATIONAL DEFENCE - DREA

Although not currently maintaining an in-house program in RST, the Defence Research Establishment, Atlantic (DREA) has contracted out research in RST. Some work was initially done on Al-base alloys, but current interests are focused on Cu-base alloys for naval applications.

ENERGY, MINES AND RESOURCES CANADA - CANMET

The Canada Center for Mineral and Energy Technology (CANMET) is in the process of starting up a program in RST. In an initial phase, four research projects have been contracted out. A project, to be conducted by Sherritt Gordon Mines Ltd., will assess the potential for roll compacting Ni flake produced by a melt extraction process. A second project addresses the consolidation of rapidly-solidified materials by high energy rate compaction techniques. Limpact Industries Ltd. will perform explosive compaction trials on pure metal powders and rapidly-solidified alloys. At the same time the Ontario Research Foundation will compact similar materials with their petro-forge. Explosive compaction develops wave velocities of 1000 m/s, whereas the

petroforge operates with a ram speed of 22 m/s. The properties of the consolidated products will be evaluated.

A contract with Sinteris Canada Inc., the only Canadian stainless steel P/M parts manufacturer, will examine the effects of rapid solidification on stainless steels with the goal of enhancing corrosion resistance and/or reducing the alloy content of stainless steel parts.

The fourth contract, with the Manitoba Research Council, will examine the corrosion fatigue behaviour of several of the important magnetic metallic glasses.

It is hoped these contracts will help to stimulate further industrial development of RST in Canada.

In parallel with its contracting activities, CANMET plans to carry out a modest program of in-house research. To this end, it is currently in the process of obtaining a melt spinner enclosed in a chamber for atmosphere control. Once set up, the equipment will be used to produce both ferrous and nonferrous materials. CANMET possesses a wide range of equipment which may be used for consolidating rapidly-solidified materials, including a 900 ton extrusion press, isostatic presses and a rolling mill, and consequently, consolidation may become a major aspect of research.

MANITOBA RESEARCH COUNCIL (MRC)

The Manitoba Research Council is moving into the field of RST with a program on metallic glasses. One project sponsored by the National Research Council (NRC) will examine the development of force transducers utilizing metallic glasses. A second project undertakes to develop distribution transformers with low loss metallic-glass cores. This project, in which Carte Electric Ltd. is participating, is jointly funded by the Department of Regional Industrial Expansion (DRIE) and the Manitoba Research Council. Because there are no facilities for producing metallic glasses at MRC, the materials are purchased from the U.S.

ONTARIO RESEARCH FOUNDATION (ORF)

The Ontario Research Foundation is maintaining an in-house research program in RST and has completed a number of projects on a contractual basis. Specialized facilities include a melt spinner for ribbon production, a 500 ton press and a petroforge which have potential for consolidating rapidly-solidified powders. The ORF plant also includes equipment for powder production,

although the current apparatus is not specifically designed to produce rapidly solidified powders. In their work, ORF personnel have gained experience in the rapid solidification of Al-, Cu-, Pb-, and Zn-base alloys, as well as in precious metals.

UNIVERSITY

Most research in RST in Canada to date has been done in the universities, and most of this is being done in the physics departments, where researchers have concentrated on the unusual electronic and magnetic properties of metallic glasses. However, at Sherbrooke, Laval and McMaster, studies of specialized techniques for the production of rapidly solidified materials are underway.

DALHOUSIE

Metallic glasses are being studied at Dalhousie University. The program, under the direction of Dr. Dunlap in the Department of Physics, has been running for four years and employs a postdoctoral research associate and three graduate students. Research subjects include determination of Mossbauer spectra, magnetization behaviour, electroresistivity, crystallization behaviour and X-ray determinations of crystalline phase structures. The group has also been studying hydrogen diffusion in metallic glasses in an effort to attain a better understanding of hydrogen bonding and how it affects magnetic properties.

A wide range of amorphous alloys has been produced on a melt spinner. Although equipped with a chamber to maintain an inert atmosphere, the chamber has seldom been used. Recently, amorphous powders have been produced by embrittling glass ribbons with hydrogen and pulverizing the material. A low-temperature anneal removes the hydrogen and restores the properties of the glass.

LAVAL

Dr. Angers in the Department of Mining and Metallurgy has been studying the production of metal powders by the rotating-electrode process for some time. More recently, with the help of a post-doctoral fellow, he has undertaken the design and construction of a centrifugal atomization unit for producing rapidly solidified powders. Construction is well advanced, and initial

trials of the system are planned for the immediate future. The immediate goal of the program will be to characterize the important parameters in powder production, rather than to investigate specific alloys.

MCGILL

By far the largest university program of research on RST is being carried out by Professor Strom-Olsen at McGill. Here, three professors, three research associates and six graduate students work on metallic glasses. The facilities, located in the Physics Department, include a melt spinner enclosed in a chamber for atmospheric control, a second melt spinner on which ribbons of 2.5 cm width have been produced, a differential scanning calorimeter for studying crystallization of metallic glasses and a powder diffraction X-ray unit for determining the structure of crystalline phases. The laboratory is also equipped to carry out measurements of Mossbauer spectra, resistivity, superconductivity, magnetic properties and hydrogen storage.

For over a decade, the program at McGill has been directed to studies of the structure and electronic properties of metallic glasses, particularly those containing zirconium. Current research is focused on structural relaxation effects as monitored by superconductivity, the development of magnetically-hard materials from metallic glasses, the development of magnetic sensors employing metallic glasses, and the determination of the hydrogen storage capabilities of metallic glasses.

MCMASTER

The use of laser surface treatments as a means of rapid solidification is being investigated by Professor Piercy in the Department of Materials Science at McMaster. In its initial phases, structures obtained by laser treatments of binary and ternary aluminum alloys will be characterized.

MONTREAL

Dr. Cochrane in the Department of Physics works closely with the group at McGill University on metallic glasses, and has studied physical, magnetic and transport properties of a wide range of glassy alloys. A post-doctoral research assistant and a graduate student work with him. Although, at present, glasses are obtained from McGill, a sputtering system for producing amorphous materials is being constructed. Sputtering yields a wider range of alloys in the amorphous form than quenching from the melt, but structural

differences exist between materials produced by the two techniques. Future work will include characterization of these structural differences.

QUEEN'S

Dr. Smith, of the Department of Metallurgical Engineering, has made use of RST in a number of projects. Rapid solidification has been used as a means of extending solid solubilities in Sn alloys with the objective of developing a grey tin which is stable at high temperatures. In other work, rapidly-solidified materials have been used in studies of the work-hardening behaviour of Hadfield Steels, and the formation of eutectic structures in Al-Si and Al-Cu alloys. In the near future, work will begin on rapidly solidified ceramics.

The rapidly solidified materials are produced by melt spinning on a 10 cm diameter copper wheel. The apparatus is equipped with a chamber so that materials may be produced in an inert atmosphere. A differential scanning calorimeter (DSC) is available for studying transformation kinetics.

SHERBROOKE

Research in RST at the University of Sherbrooke is developing as an offshoot of a plasma research program in the Department of Mechanical Engineering. It has been found that coatings applied by plasma spraying can be rapidly quenched by directing a high-velocity inert gas stream onto the freshly-deposited material. By this technique, it has been possible to produce a sound amorphous coating of a commercial Ni-base alloy, Amdry 915, on mild steel. Future work is likely to be aimed at developing rapidly solidified surface coatings by plasma spraying. The production of thick sections of rapidly-solidified material by plasma spraying will also be investigated.

SIMON FRASER

Dr. Ballentine of the Physics Department is carrying out theoretical calculations on the electrical conductivity and electron densities in liquid metals and amorphous structures. Work has also been done on the superconductivity of amorphous metals.

TORONTO

Dr. Aust of the Department of Metallurgy and Materials Science has been actively researching the corrosion behaviour of iron- and nickel-base metallic glasses for a number of years. His research seeks to understand the role of the chemical and structural characteristics of glasses in determining their corrosion behaviour. Structural studies of metallic glasses have also been carried out in collaboration with Japanese scientists. Because there are no facilities for producing metallic glasses at the University of Toronto, materials must be obtained from outside sources.

CONCLUSIONS

Rapid solidification technology is developing rapidly throughout the world. However, as yet, there has been little development of RST in Canada. Alcan is the only Canadian industrial organization currently pursuing an independent program of research in materials and process development in RST. Canada has been left far behind not only by the major industrial nations of the world such as Japan, United States, Germany and Britain, but also by such countries as Switzerland, Sweden, Norway and India where well-developed programs in RST have been established.

There is some Canadian work on metallic glasses in progress. The interest of Canadian utilities in developing and testing prototype transformers containing metallic-glass cores is an important development and may be taken as an indication that this application of RST will soon be commercially viable. Because 200 000 tons of silicon-iron are produced in North America annually (2), a very large market is at stake, and there is a genuine need for some Canadian expertise in this application. The magnetic and physical properties of metallic glasses are being explored in a number of university projects and the experience gained in this work is a valuable step towards this goal.

There are also many potential applications for rapidly-solidified crystalline materials, but Canadian laboratories have been slow to initiate work in the field. Although there have been a number of preliminary investigations, primarily at the Ontario Research Foundation, aside from Alcan's work on aluminum, there has been no program to design and process crystalline materials by rapid solidification to enhance material properties. The development of microcrystalline materials probably offers the greatest industrial

potential of RST, and there is a definite need for specific research programs in this area.

World-wide, various rapid solidification processes have been developed, and the technique of melt spinning has been used on a laboratory basis in Canada. Again, excepting the developments at Alcan, few other methods of rapid solidification have been employed in Canada, although the projects at Laval, Sherbrooke and McMaster Universities exploring centrifugal atomization, plasma spraying, and laser surface treatments respectively may lead to useful developments. One of the greatest problems hindering the growth of rapid solidification in Canada is the lack of facilities for producing rapidly solidified powder. Such facilities should be established to give impetus to the development and evaluation of new alloys and microstructures through rapid solidification.

For Canada to keep pace with the development of RST throughout the world, the following steps should be taken:

1. Ongoing research in metallic glasses in Canadian universities should continue to be supported, and a liaison between industry and the universities promoted; a greater applications orientation to current research programs should be encouraged.
2. Programs to develop new crystalline alloys and microstructures through rapid solidification should be initiated immediately. Ideally, such programs should be carried out by industry, however, in view of the slow response of Canadian industry to the development of RST, government laboratories must take the lead in initiating research.
3. The availability of facilities for producing rapidly-solidified materials is a prerequisite for any developmental work in this field. Although melt spinning equipment is relatively inexpensive, the construction of experimental apparatus for gas atomization, which may be required for developing rapidly-solidified crystalline materials, may cost in excess of \$100 000. Industry will consider such an expense to have a high risk when the technology is unproven. Strong consideration should be given to establishing a central facility for rapid solidification to which industry would have access. Such a facility would reduce the initial expense of exploratory work in RST and remove a major impediment to industrial participation in research.
4. Finally, there is a need for collaboration between engineers familiar with materials applications and property requirements and those familiar with

the structural and property enhancement which may be obtained through rapid solidification. The liaison between universities, government and industry could be improved by workshops, seminars and plant visits.

REFERENCES

1. Collins, L.E. "Overview of Rapid Solidification Technology"; Division Report MRP/PMRL 84-62(J); CANMET, Energy, Mines and Resources Canada; 1984.
2. Irving, R.R. Iron Age 226:14:47; 1983.

Table 1 - Canadian organizations developing rapid solidification technology

Organization	Contact	Address
<u>INDUSTRY</u>		
1. Alcan International Ltd.	D. Lloyd	Alcan Research Laboratories P.O. Box 8400 Kingston, Ontario K7L 4L4
2. Canadian Electrical Association	E. Ezer	Suite 580 1 Westmount Square Montreal, P.Q. H3Z 2P9
3. Hydro Québec	R. Roberge	Institut de Recherches d'Hydro-Québec IREQ 1800 Mtée Ste Julie Varennnes, P.Q. J0L 2V0
4. Saskatchewan Power Corp.	D. Walker	2025 Victoria Ave. Regina, Sask. S4P 0S1
5. Sigma Security Inc.	U. Schilcher	Suite 103 562 Eglinton Ave. E. Toronto, Ont. M4P 1B9

Table 1 (cont'd)

Organization	Contact	Address
<u>GOVERNMENT</u>		
1. Dept. of National Defence	R. Hollingshead	Defence Research Establish- ment, Atlantic Dartmouth, N.S.
2. Energy, Mines and Resources Canada	L. Collins	CANMET 568 Booth St. Ottawa, Ont. K1A 0G1
3. Manitoba Research Council	K. Tandon	1329 Niakwa Rd. Winnipeg, Man. R2J 3T4
4. Ontario Research Foundation	M. Gibbon	Sheridan Park Research Community Mississauga, Ont., L5K 1B3

Table 1 (cont'd)

Organization	Contact	Address
<u>UNIVERSITIES</u>		
1. Dalhousie	R. Dunlap	Department of Physics Dalhousie University Halifax, Nova Scotia B3H 3J5
2. Laval	R. Angers	Département des mines et métallurgie Université Laval Québec, P.Q. G1K 7P4
3. McGill	J.O. Strom-Olsen	Rutherford Physics Bldg. McGill University 3600 University St. Montreal, P.Q. H3A 2T8
4. McMaster	G.R. Piercy	Dept. of Metallurgy and Materials Science McMaster University 1280 Main St. W. Hamilton, Ont. L8S 4M1
5. Montréal	R.W. Cochrane	Département de Physique Université de Montréal C.P. 6128, Succ. A Montréal, P.Q. H3C 3J7

Table 1 (cont'd)

Organization	Contact	Address
<u>UNIVERSITIES</u> (cont'd)		
6. Queen's	R.W. Smith	Department of Metallurgical Engineering Queen's University Kingston, Ont, K7L 3N6
7. Sherbrooke	C. Roy	Département de génie mécanique Faculté des sciences appliquées Université de Sherbrooke Sherbrooke, P.Q. J1K 2R1
8. Simon Fraser	L.E. Ballentine	Department of Physics Simon Fraser University Burnaby, B.C. V4A 1S6
9. Toronto	K. Aust	Dept. of Metallurgy and Materials Sciences University of Toronto Toronto, Ont. M5S 1A4